

Modeling Growth of Fatigue Cracks Which Originate at Rivet Holes

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When a structural component is subjected to repeated stress cycles, it can fail at stresses which are well below the tensile strength of the material. The processes leading to this failure are termed "fatigue".

Instances of fatigue failure in aircraft have become an increasing concern. The cracks leading to failure often originate at rivet holes and then grow in response to stress cycles which occur during operation of the aircraft. A necessary step to preventing failures in today's fleet of ageing aircraft is to increase the frequency and quality of inspections; steps have already been taken in this direction. There is also a need for modeling of fatigue crack growth in aircraft structures so that improvements in design can be established and predictions of the life of components can be made.

The purpose of this study is to provide a method to accurately predict the growth of fatigue cracks and to use this method to make predictions about the life of aircraft structural components. The method relies on the formulation and numerical solution of a singular integral equation(s) for an arbitrarily shaped crack(s) which propagate in response to the applied loading. Of special interest to the ageing aircraft studies are cracks which originate at circular holes (i.e. rivet holes), but other crack geometries can be treated equally as well.

The starting point for the analysis is the fundamental solution for a dislocation in an unbounded medium. The discontinuity in displacements across the crack surface is then represented by a continuous distribution of these dislocations. The dislocation density is determined by requiring the tractions on the crack surfaces to have prescribed (known) values. This results in a singular integral equation for the dislocation density. To render the solution to this equation unique, it is necessary to enforce the condition that the displacements are single valued everywhere in the cut plane.

To obtain a numerical solution to the integral equation, the crack line is represented by a sequence of piecewise linear segments. The dislocation density at the nodes joining these segments are taken as the unknown quantities, with the density

over each element given in terms of these nodal values. Collocation is then used to obtain a system of linear algebraic equations to be solved for the approximate dislocation density.

We have carried out the analysis and developed a code for isolated cracks in unbounded domains and for isolated cracks originating from holes in unbounded domains. Results of several test cases for straight and curved cracks have been compared with known solutions and excellent agreement has been found. Preliminary studies for growing (curving) cracks have also been performed to demonstrate the usefulness of the method. These preliminary results have demonstrated the ease of application of the method and its efficiency.

The next step in the study is to model interacting cracks and cracks in finite domains. To do this we will retain the same modeling scheme for the cracks, and account for the finite domain using standard boundary element techniques. Because the problem is linear, the boundary element method and the distributed dislocation method can be coupled directly using the principle of superposition.

After the development of this capability, the growth of fatigue cracks in thin structures will be investigated. As emphasized previously, attention will be given to cracks which originate at rivet holes. The growth of these cracks will be modeled, fully accounting for interactions with other cracks and boundaries. The results of these studies will be used to predict the fatigue life of aircraft structures.